Numerical Study of Flow Through a Sudden Expansion using OpenFOAM

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Synopsis

This study investigates laminar incompressible flow through a sudden expansion channel, with and without porous effects, using the **porousSimpleFoam** solver in OpenFOAM 7. The main objective is to evaluate the influence of Reynolds number and expansion height on pressure drop, vortex formation, and flow uniformity, providing insights for the design of efficient diffusers and ducts. A two-dimensional domain with an inlet width of 0.5 m and downstream expansion heights of 0.7 m, 0.9 m, and 1.0 m was constructed using **blockMesh**, and simulations were performed at Reynolds numbers of 100, 1000, and 5000. Porosity effects were incorporated via the Darcy–Forchheimer model to assess their impact on flow characteristics.
Results show that pressure drop increases with Reynolds number due to higher momentum transport, highlighting the importance of operating conditions in expansion channel design. Larger expansion heights amplify adverse pressure gradients, resulting in stronger vortices and longer recirculation zones. At smaller heights, vortices remain weak and confined near the expansion corner, while at larger heights and higher Reynolds numbers, they become more intense and occupy a greater portion of the downstream flow. These vortices affect reattachment length, pressure recovery, and flow mixing, underlining the need for accurate prediction of vortex behaviour to minimize energy losses. The introduction of porosity significantly alters flow dynamics. Porous walls dissipate momentum, reducing recirculation length and promoting a more uniform velocity distribution. Compared with non-porous channels, porous expansions enhance flow uniformity, improve pressure recovery, and mitigate regions of low velocity, demonstrating their potential for energy-efficient duct and diffuser designs.
Keyword: Expansion, Reynolds Number, Porosity

1. Introduction

Sudden expansions in duct flow are common in engineering systems such as diffusers, exhaust pipes, and ventilation ducts. The abrupt change in cross-sectional area leads to flow separation, recirculation zones, and increased energy dissipation due to adverse pressure gradients. Quantifying the resulting pressure loss is essential for efficient system design. Computational Fluid Dynamics (CFD) enables detailed analysis of such flows, allowing parametric variations in geometry and flow conditions to be studied without costly experiments. OpenFOAM, as an open-source CFD platform, provides flexibility for customised simulations. This work examines the effect of Reynolds number and downstream height on the pressure drop in a planar sudden expansion, with validation against Moallemi & Brinkerhoff's [1] numerical study. Porosityinduced flow resistance is applied in heat exchangers and cooling channels for uniform heat transfer, in packed-bed reactors for better mixing, in biomedical devices to regulate shear stresses, in combustor liners for damping and stabilisation, and in filtration or groundwater systems to control transport. Overall, porosity is used to achieve uniform flow, reduce instabilities, and enhance efficiency in thermal, chemical, biological, and fluid systems [2,3].

2. Problem Definition

The problem consists of incompressible laminar flow through a two-dimensional sudden expansion channel. The computational domain is 2 m long in the x-direction, with an inlet section of height 0.5 m and a downstream section of height H. The expansion occurs at x=1 m = 1. The depth of the channel (perpendicular to the x–y plane) is considered as 0.01 m, making it a quasi-2D flow domain.

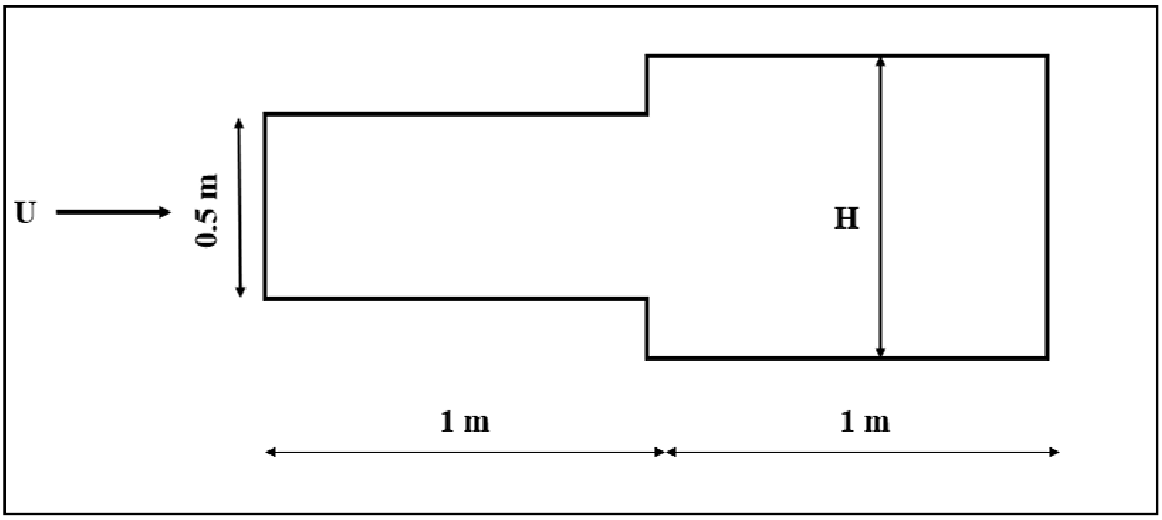

Figure1: Problem geometry